DIAGNOSING THE EFFECT OF THE MJO ON THE DIURNAL CYCLE OF RAINFALL IN THE SOUTHERN HEMISPHERE

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1. INTRODUCTION

Planning of our day to day activities is highly dependent on the predictions of meteorological variables (mostly temperature, rainfall and humidity) from Numerical Weather Prediction (NWP) models. Of these parameters, rainfall has a very chaotic nature, with various modes of variation in time (diurnal, synoptic, intra-seasonal, seasonal, inter-annual to annual) as well as in space e.g. catchments to regional, global. Previous studies (Lin et al. 2000, Yang and Slingo 2001, Dai and Trenberth 2004, Zhou and Wang 2006) have shown that the annual cycle is well represented in many respects in regional and global atmospheric general circulation models. In contrast, models have experienced fundamental difficulties in capturing the diurnal cycle.

Northern Australia has a prominent diurnal cycle of rainfall and there is substantial intra-seasonal variation during the Australian summer season (DJF). Using the CEOP (Koike 2004) EOP3 period dataset at Darwin Australia for DJF (2002/03) season, the diurnal cycle of rainfall (normalized by its mean) composited from in situ observations (Darwin airport) and from four different NWP models (BMRC, UKMO, JMA, and NCEP) rainfall product (MOLTS) is shown in Fig. 1. The result shows two peaks (night and afternoon) in the in situ observations, with the night-time (02-03 LT) peak stronger than the afternoon (16-17 LT). It is seen that the all four models have considerable difficulty in producing the night time peak whereas the afternoon peak is up to 4 hours earlier than in the observations. In addition, all four models underestimate the rainfall. This is similar to findings for the Maritime Continent by Yang and Slingo (2001).

The present study is focused on increasing our understanding of the cause of the night peak at Darwin and its surrounding regions and the impact of large weather circulations on the diurnal cycle of rainfall by utilizing higher temporal and spatial scale datasets. As has been found previously, the idealized view of a rainfall maximum in the early morning over open oceans and in afternoon/early evening over continents is modified by orography (Satomura 2000, Ohsawa et al. 2001) and the initiation, propagation and decay of mesoscale convective systems (Mori et al. 2004, Tian et al. 2005, Ichikawa and Yasunari 2008). We also intend to provide a foundation for the validation of future results from regional scale numerical model simulations.

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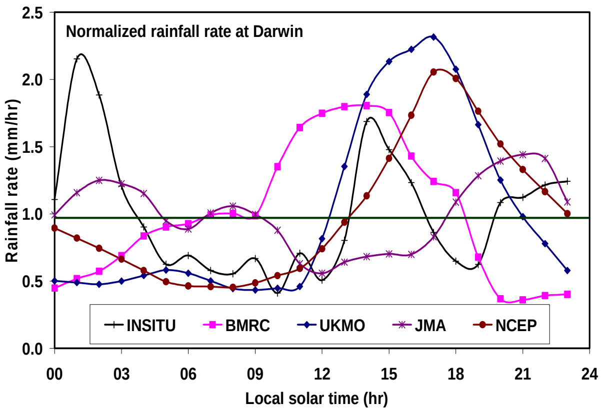

Figure 1. Diurnal cycle of rainfall (normalized by its mean) for DJF season of CEOP-EOP3 period at Darwin, Australia.

2. DATA & METHODS

Hourly insitu rainfall observation from Darwin airport, Australia for 7 full wet seasons (DJF, 2001-2008) and the Real-time Multivariate MJO (RMM) index developed by Wheeler and Hendon (2004) (WH04) have been used. The index is based on a pair of EOFs of the combined fields of near-equatorially (15°S-15°N) averaged 850 hPa zonal wind, 200 hPa zonal wind and OLR data (called RMM1 and RMM2). When viewed in the two dimensional phase space defined by RMM1 and RMM2 (see Fig. 7 WH04), the eastward propagation of the MJO can be categorized into 8 phases of MJO, each corresponding to the geographical position of its active convective center. At Darwin and nearby locations the MJO is active when it is in phases 4,5,6,7 and inactive in other phases. A "weak" MJO period has also been defined when the amplitude ($\sqrt{RMM1^2 + RMM2^2}$) is less than 1. The hourly rainfall data were classified according to three categories of MJO (active, inactive & weak) and corresponding composite diurnal cycle were derived.

In addition to site observations, the TRMM 3G68_V6 hourly gridded text (ASCII) product containing TRMM instrumental rain estimates at 0.25° x 0.25° horizontal resolution for 10 full wet seasons (DJF, 1998-2008) has also been used. The TRMM 3G68_V6 (ftp://trmmopen.gsfc.nasa.gov/pub/) consists of total pixels, rainy pixels, mean rain rate (mm/hr) and percentage of rainfall calculated to be convective from the 2A12 (TMI), 2A25 (PR) and 2B31 (TMI-PR combined) algorithms merged into a single daily file. Although it covers only small regions at a time and has coarse sampling time intervals, it is assumed to be providing the most reliable rainfall estimate available for this purpose. A 225 km x 225 km spatial region centred at Darwin has been used to diagnose the impact of MJO on the diurnal cycle of rainfall over land, coastal and ocean regions. Each hourly rainfall is classified into the three categories of MJO (active, inactive and weak). Composite hourly datasets were compiled for the diurnal cycle of rainfall when the MJO was active, inactive and weak over each grid square (at local time) based only on the TRMM PR sensor. The diurnal cycle is smoothed by applying a 4-h running mean to reduce the spatial variability in sampling (Negri et al 2002). EOF analysis (Kikuchi and Wang 2008) is used to explain the spatial and temporal variability.

3. RESULTS

Both peaks (night and afternoon) are evident in the in situ observation (Fig.2) and in the TRMM-PR observation (not shown) from seven DJF seasons. The rainfall during the MJO active phase accounts for 46% of the total, the inactive phase for 24%, and 30% when MJO is weak. On categorizing the diurnal cycle by the three MJO phases (Fig. 2), it is seen that the night time peak is more apparent when the MJO is active. This is related to the fact that at night the convection is centered over the ocean and propagated to the coastal region (Darwin) by strong westerly winds. In contrast, the afternoon peak is stronger during the MJO inactive phase. Thus this afternoon peak is caused by the atmospheric instability due to the direct solar radiation, suggesting that high Convective Available Potential Energy (CAPE) conditions are responsible for afternoon rainfall. It has been also found that the nature of modulation of the diurnal cycle by MJO is the same if the season is defined as JFM rather than DJF. The impact of active and break phases of monsoon (with definitions based on OLR anomaly and sign of the zonal wind rather than MJO phases) is similar to the above results, suggesting a strong relationship between active monsoon and active MJO.

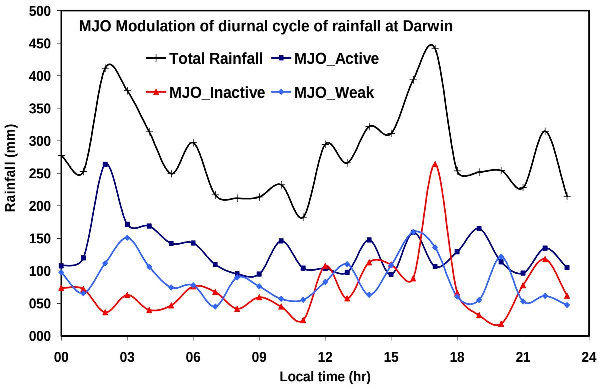

Figure 2. Diurnal cycle of total rainfall of in situ observation from 7 full wet seasons (DJF, 2001-2008) at Darwin Australia and its categorization according to three phases of the MJO.

The spatial distribution of climatological DJF seasons (10 years) total rainfall (Fig. 3) in a 225 km x 225 km region centered at Darwin from the TRMM-PR reveals the coastal area between the mainland and the Tiwi Islands of Northern Australia receives much rainfall. This rainfall is widely distributed during active days while it is mainly over the inland regions during inactive days of the MJO. The western part of Tiwi Islands and nearby coastal regions receives more rainfall when MJO is suppressed (weak).

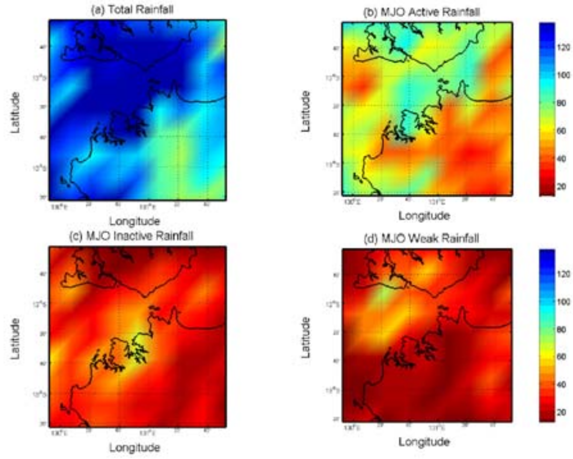

Figure 3. Distribution of climatological DJF mean rainfall derived from 10 years of DJF data for (a) total rainfall (b) MJO active rainfall (c) inactive rainfall and (d) weak rainfall.

An attempt has been made to explain the characteristics of diurnal cycle by using EOF analysis. Kikuchi and Wang (2008) have used this method to successfully explain the principal features of the diurnal cycle of rainfall in the global tropics. Only results of first two EOFs, which explain more than 60% of total variance (Fig. 4a & 5a), are presented here. A clear land, sea and island contrast can be seen in EOF1s (Fig 4c & 5c) reflecting the nature of atmospheric responses to solar radiation.

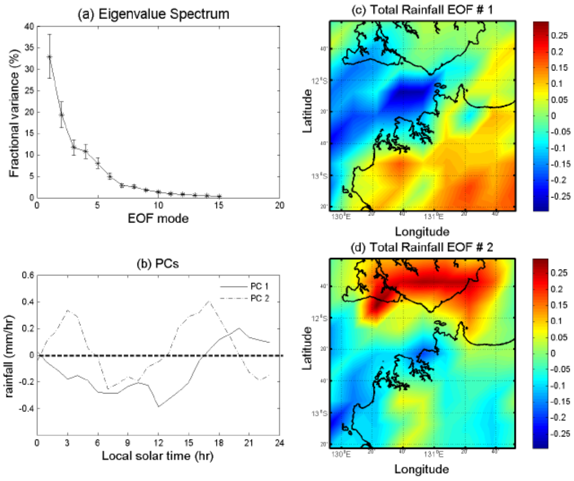

Figure 4. EOF analysis of the mean diurnal cycle (1998-2008, DJF) derived from total rainfall (TRMM PR).

The maximum rainfall over coastal regions is occurring in the morning (0600-1000 LT) and inland during the late afternoon (1800 LT).. Kikuchi and Wang (2008) have also found the same features in their analysis of tropical rainfall. Over the Tiwi Islands, EOF1 is nearly zero and EOF2 has positive values in early morning and in afternoon showing maximum rainfall occurring in the afternoon (0300 LT). The phase difference in the peak of rainfall between the Island and mainland of Australia is also clear from the EOF1 and 2 with their corresponding PCs.

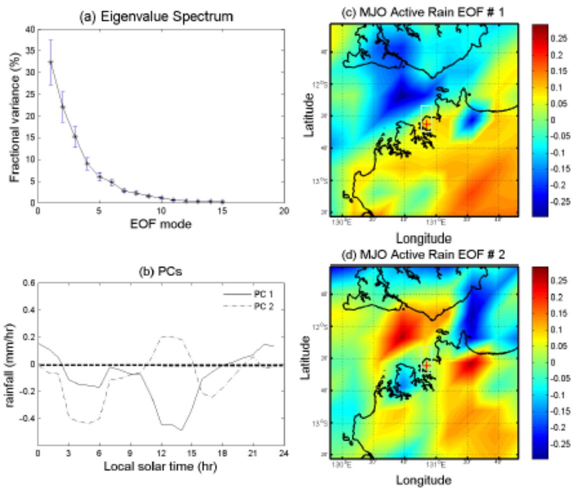

Figure 5. Same as Fig 4, but for MJO active days mean diurnal rainfall.

The EOF analysis of diurnal cycle during MJO active days only (Fig 5) shows that rainfall during the early morning (0300 – 0600 LT) is enhanced over the islands and coastal region but less convection is observed over the mainland and islands during the afternoon (1200 – 1500 LT). This feature of a night time increase in rainfall rather than during the afternoon is also seen at Darwin (red cross, Fig 5 c & d). Interestingly the result is opposite for sea regions with suppression of rainfall at night and more in the afternoon.

During the inactive days of MJO, an early afternoon (1200 LT) peak in rainfall has been noted (not shown) at Darwin and inland in the EOF analysis. In contrast, a peak has been seen during early morning around the southwest of the Islands which propagates towards the coastal region near Darwin.

4. SUMMARY

Through the analysis of long term high temporal and spatial resolution rainfall data from both in situ and TRMM satellite observations at Darwin, Australia and nearby regions, it has been found that the MJO is responsible for enhancement of night time rainfall over inland regions and nearby small islands. Since NWP models have great difficulty in simulating the MJO behavior, these models could not able to produce night rainfall in a composite diurnal cycle. The features of diurnal cycle have been well resolved by EOF analysis and show the difference of response to the atmospheric heating over continental, coastal and island regions. Only the amplitude of the diurnal cycle is modulated by different stages of MJO and there is very little or no impact on the phase.

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